

# From Static to Dynamic System estimation:

## The role of bus dynamics

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# Presentation Outline

- Static State Estimation Overview
- Problems with Static State Estimation
- Dynamic Estimation of Static State
- DSE Implementation
- Performance

# Power System State Estimation Overview

- What our measurements are telling us
  - Current flows, current injections, power flows, power injections, voltages
  - Inaccurate & corrupted measurements
- Power System Static State
  - All network measurements function of static state,  $\delta V$
  - Voltage phasor magnitude angle and magnitude
- Redundant measurements
  - $N_{\text{measurements}} \geq 2 \times N_{\text{states}}$
  - Filter out some of the measurement noise

# Power System State Estimation Overview - continued

- Handle grossly inaccurate (bad) data
  - Detect: Chi-square test
  - Identify: Weighted residual analysis
  - Remove bad data from measurement vector
- Observability Analysis
  - May remove redundancy of some states
  - May remove all data dependent on some states (unobservable)
  - Only try to estimate observable states

# Problems with Static Estimation

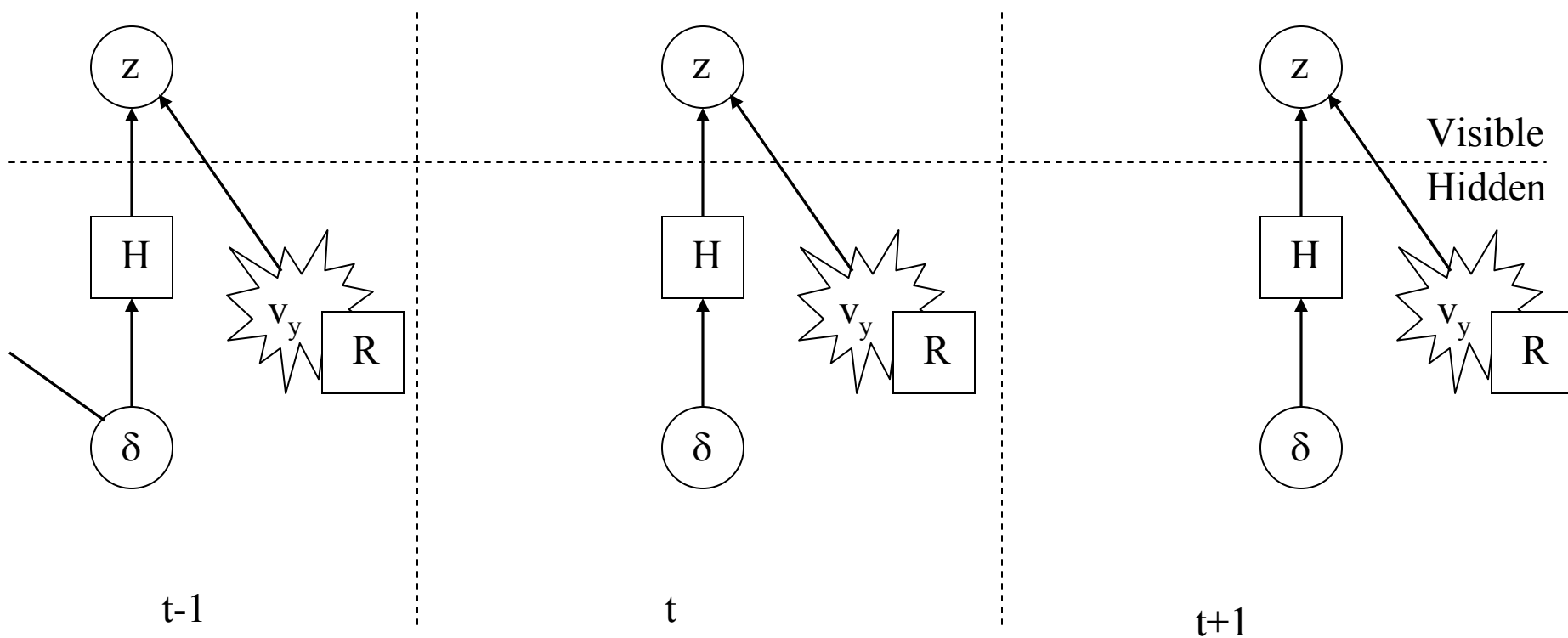
- Result entirely dependent on single snapshot of data
  - Fast network transients
  - Dynamically estimating network dynamics is difficult
- Observability vulnerable to
  - Loss of critical measurement
  - Loss of critical pair
- Accuracy vulnerable to
  - Loss of redundancy

# Problems with Static Estimation

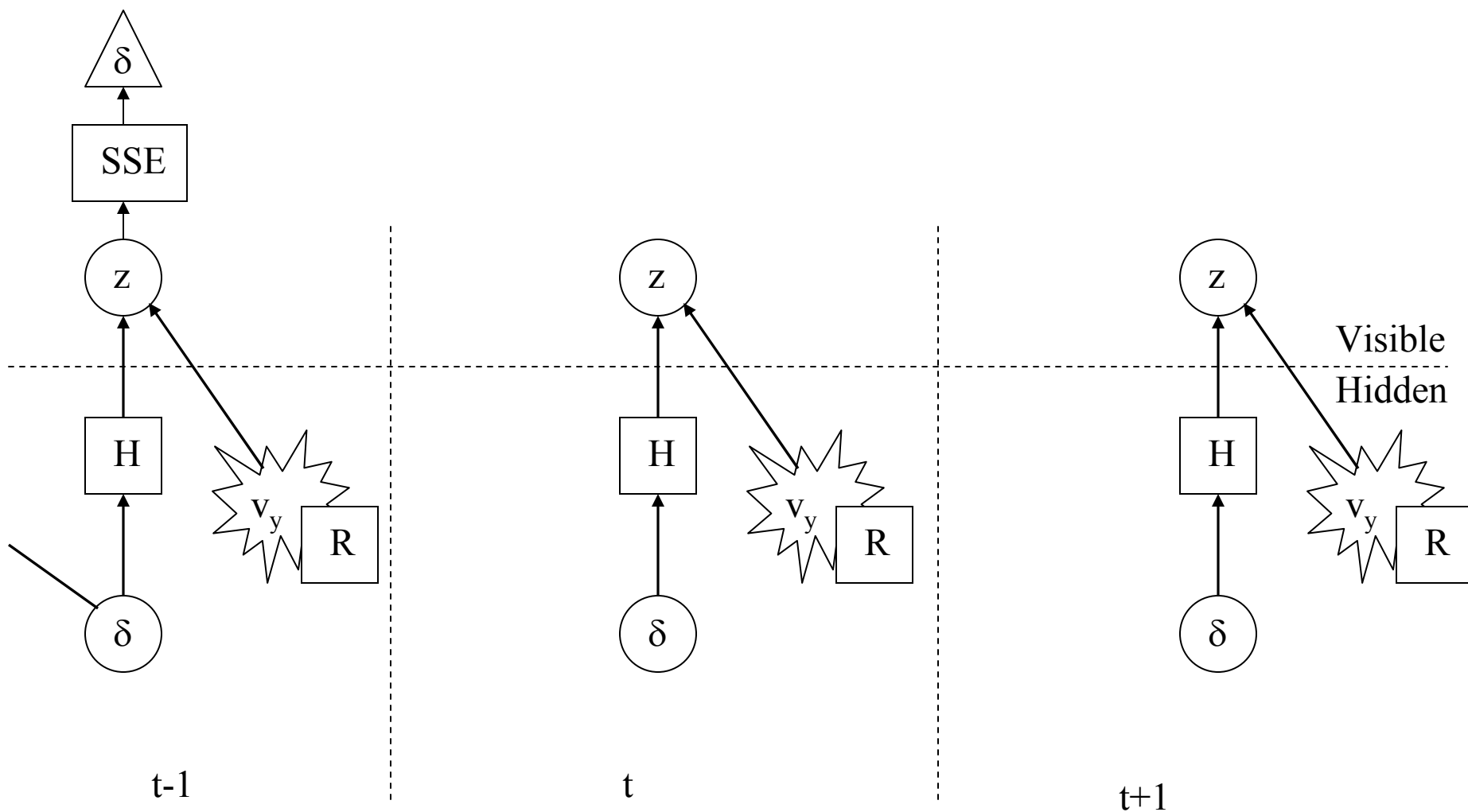
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Static SE only sees the network, not what is attached to it

# Static Estimation

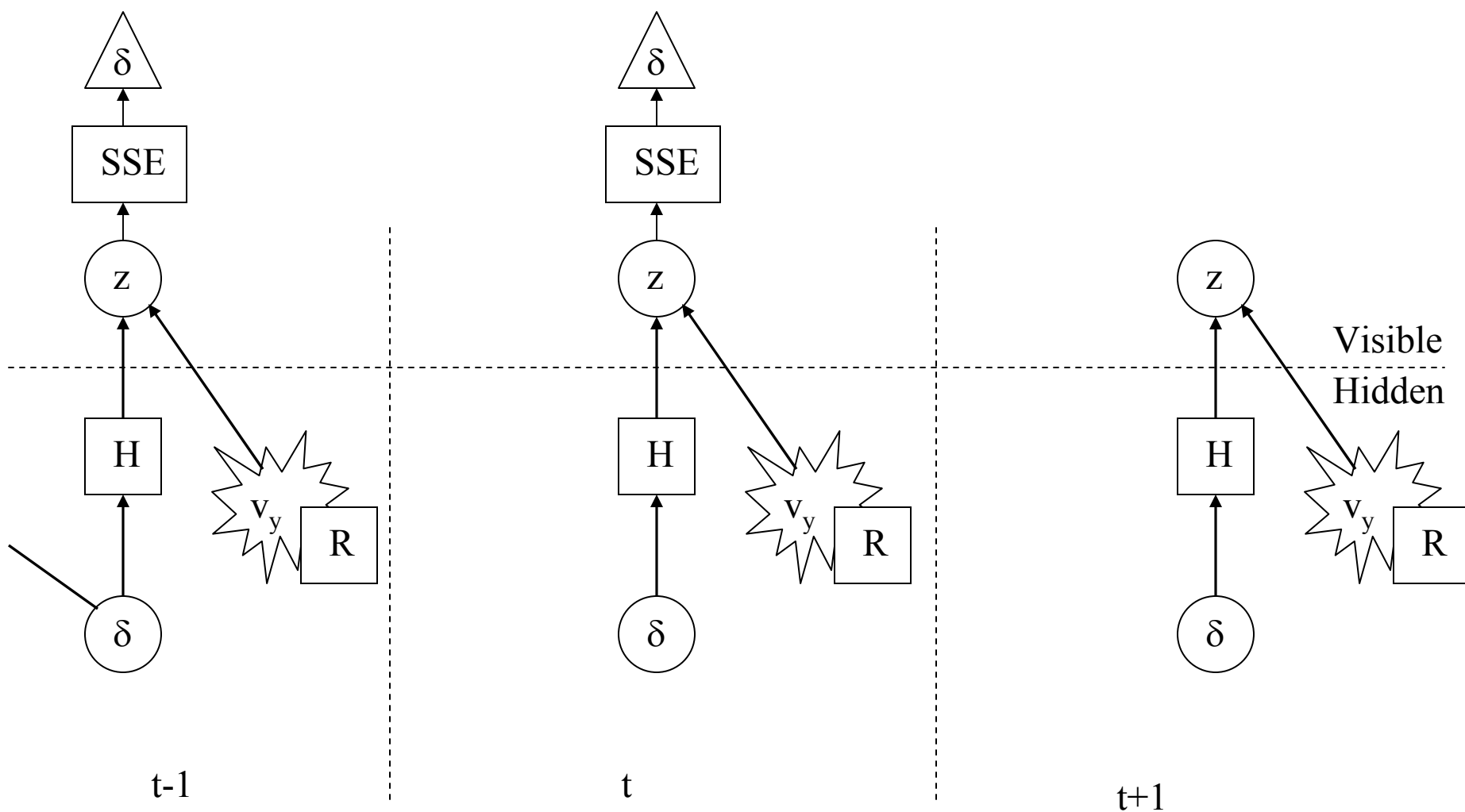


# Static Estimation

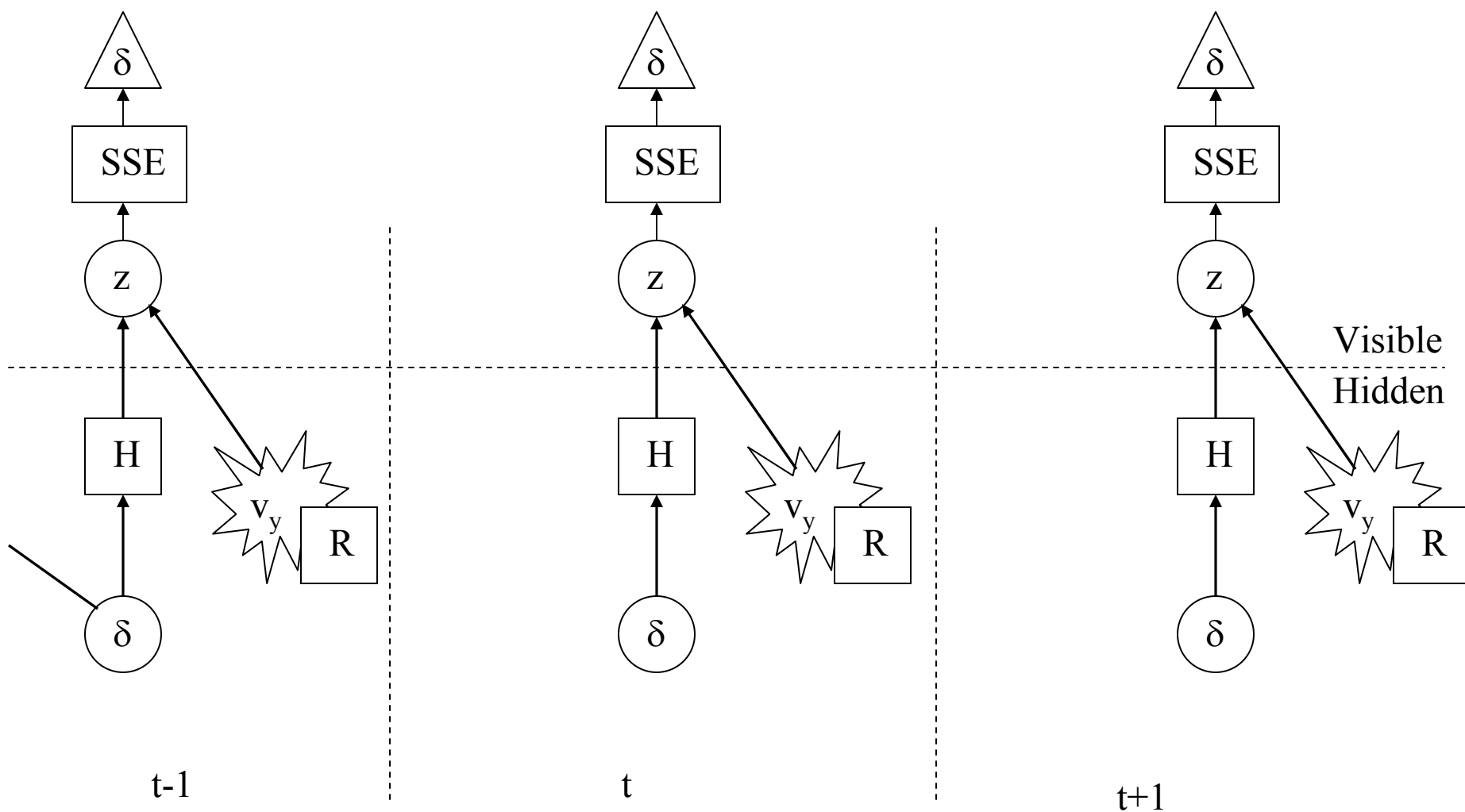




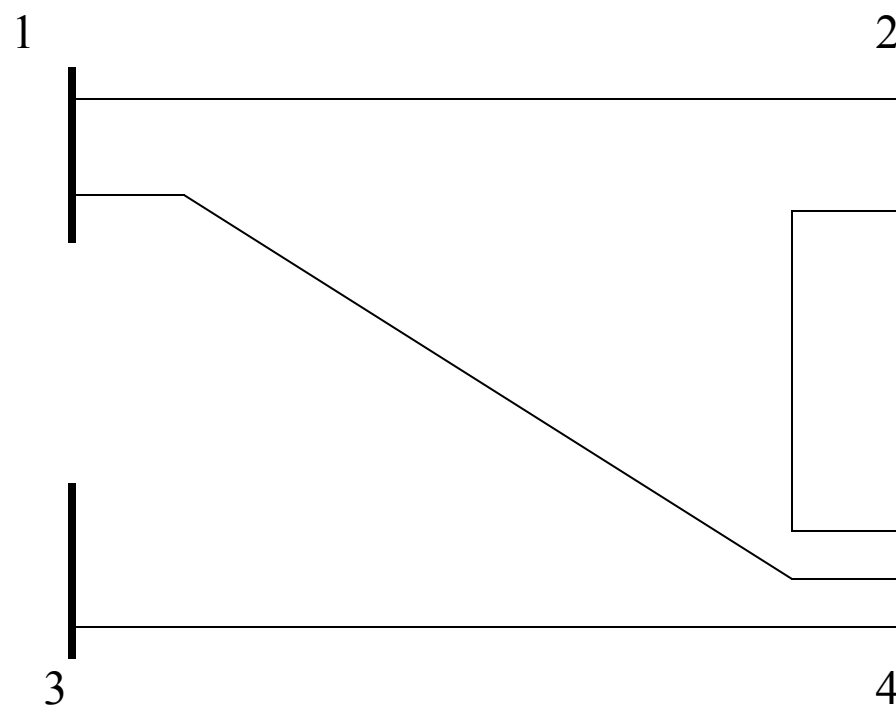
## Static Estimation



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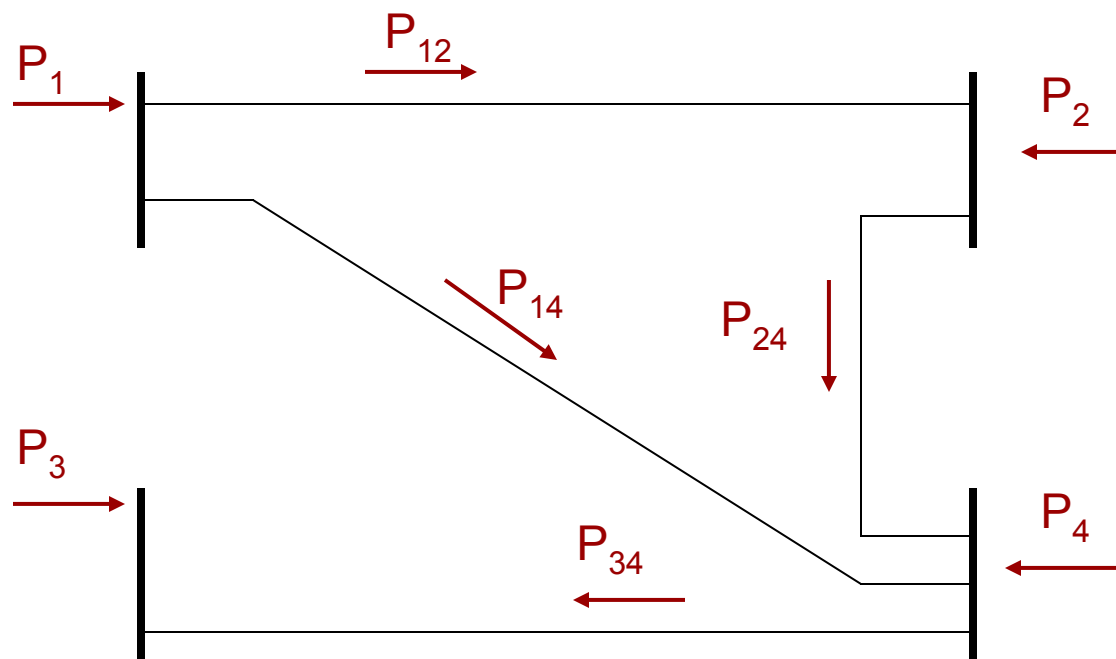


# The Network

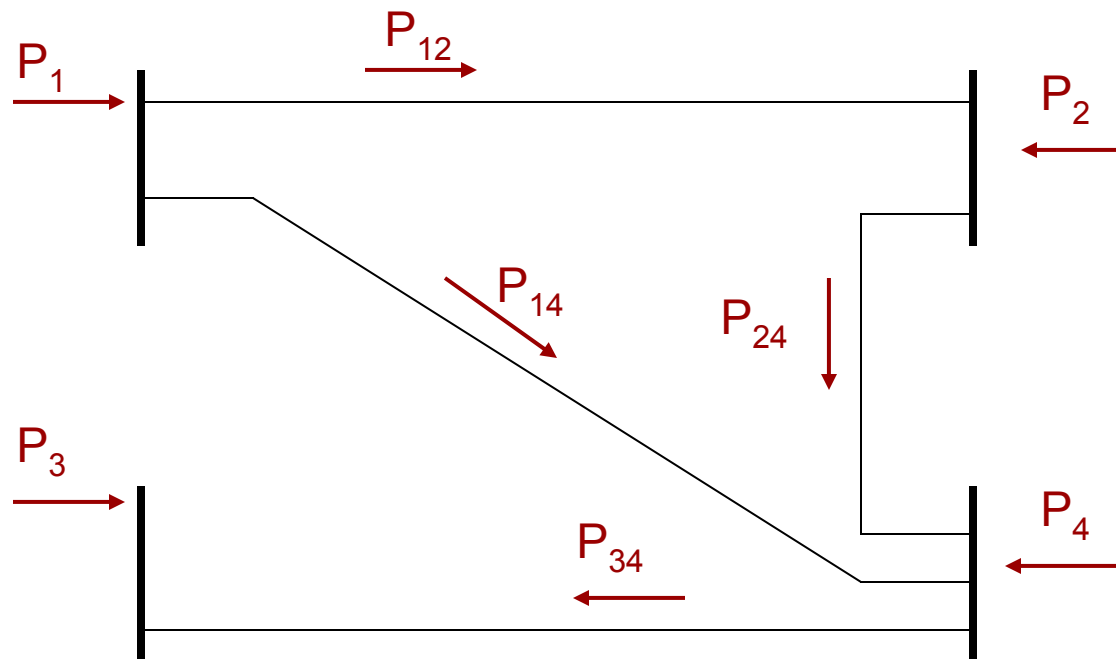


# The Network

## measurements



# The Network measurements

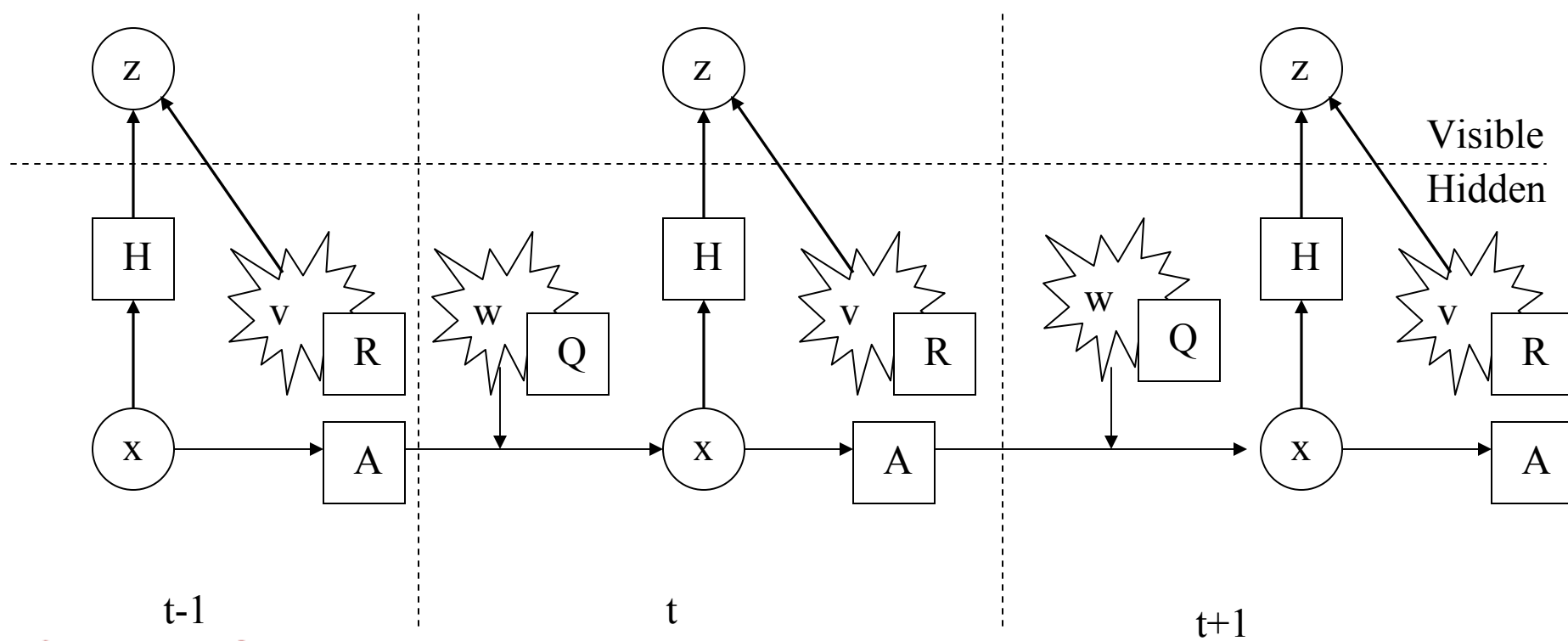


At any time, any of the  
measurements may be missing

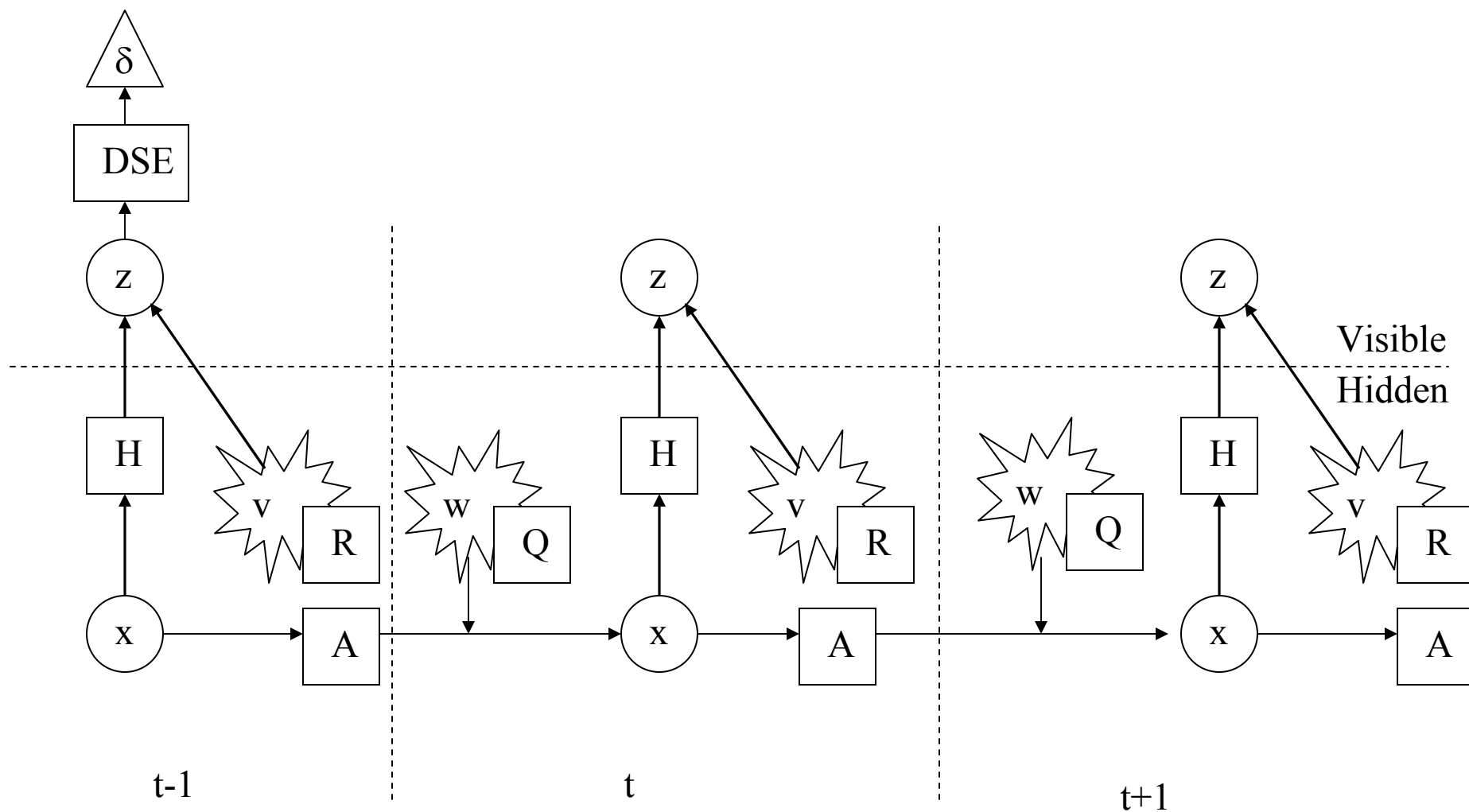
## Dynamic State Estimation of Static State

- Time constants of attached loads and GTG systems
  - Slower time constants
  - Dynamic estimation of attached systems is feasible
- Effectively provide additional redundancy
  - Power/current bus injections
  - Comes from modeling (no extra hardware required)
  - Models time behavior (correlates measurements across snapshots)

# Dynamic Estimation

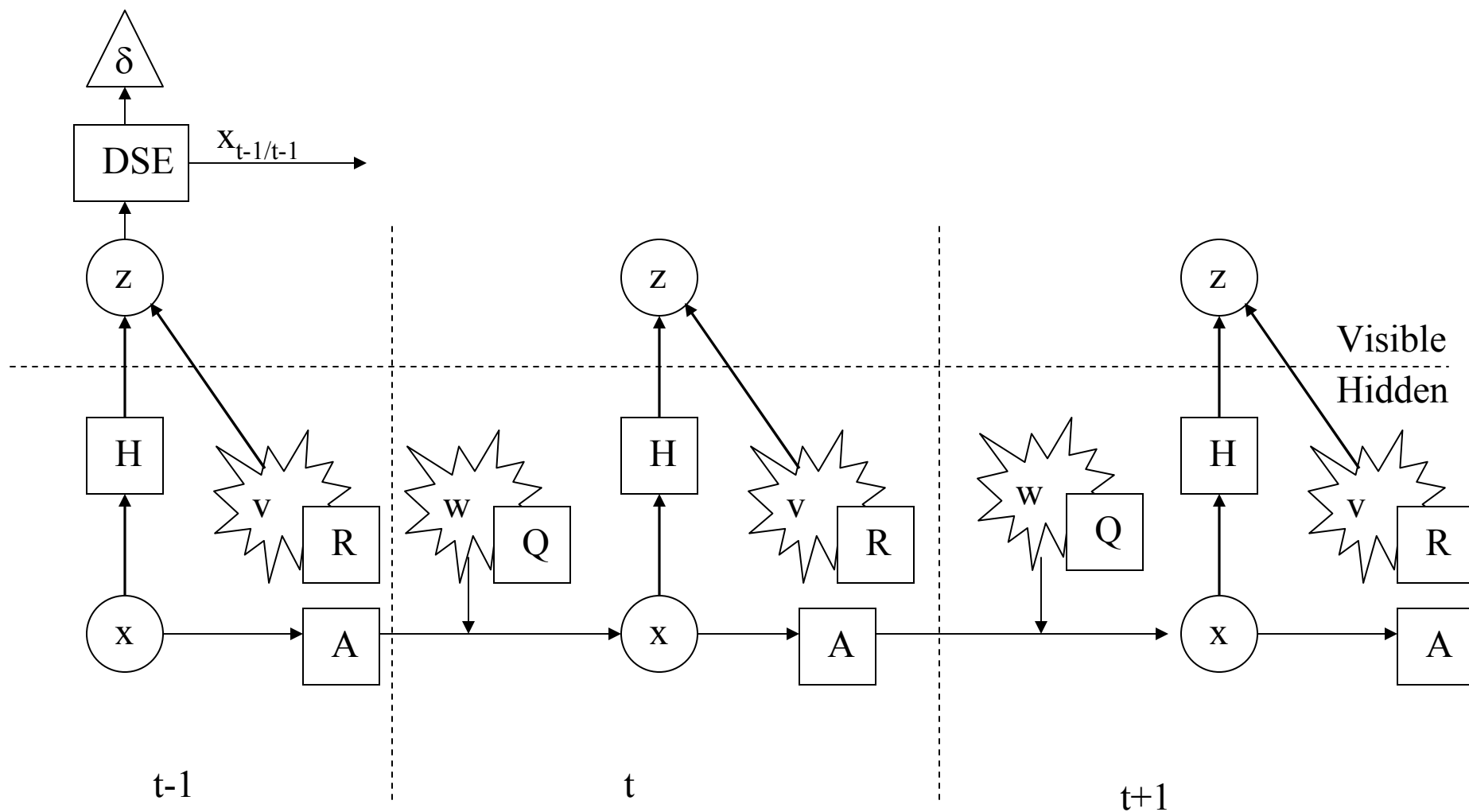


# Dynamic Estimation

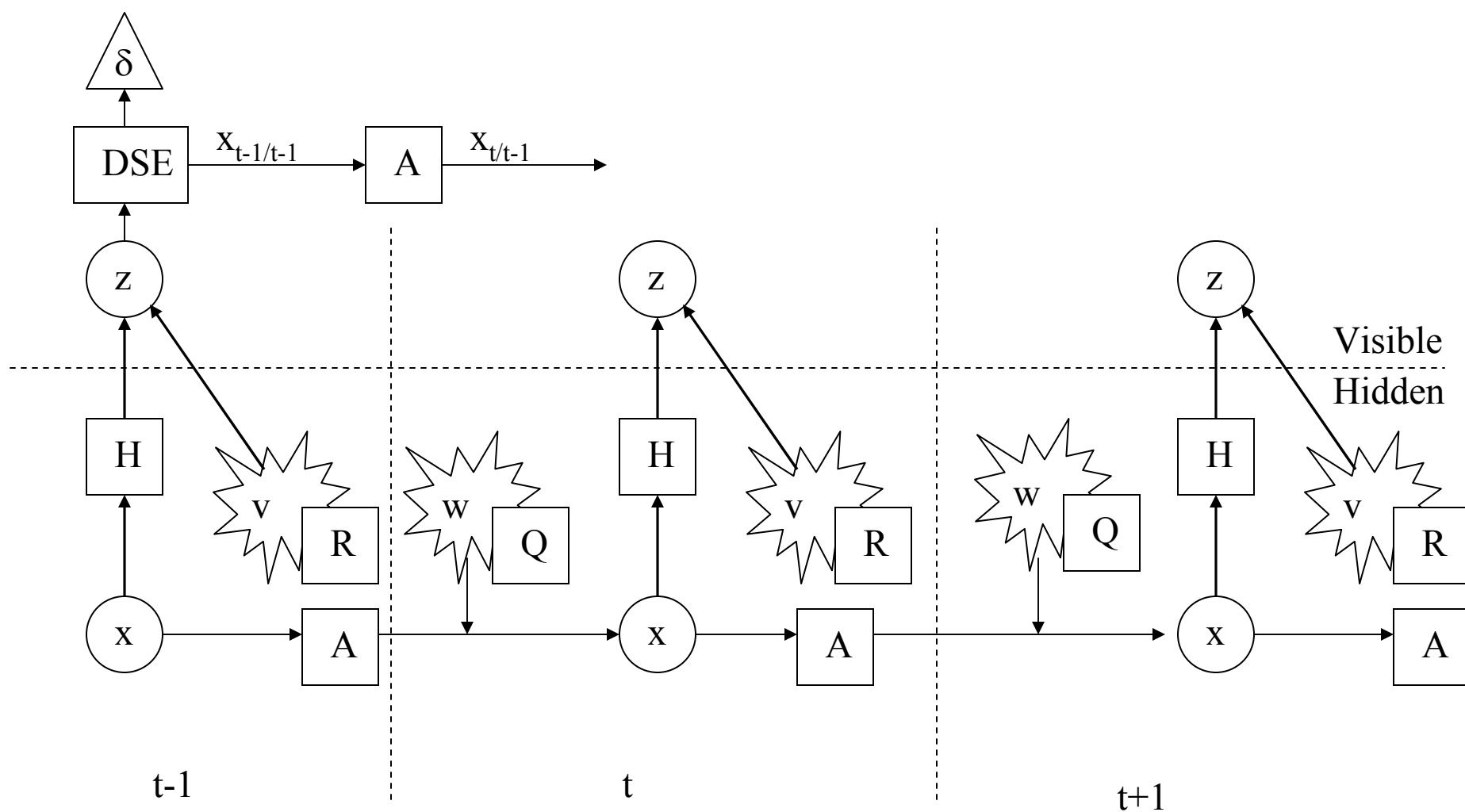




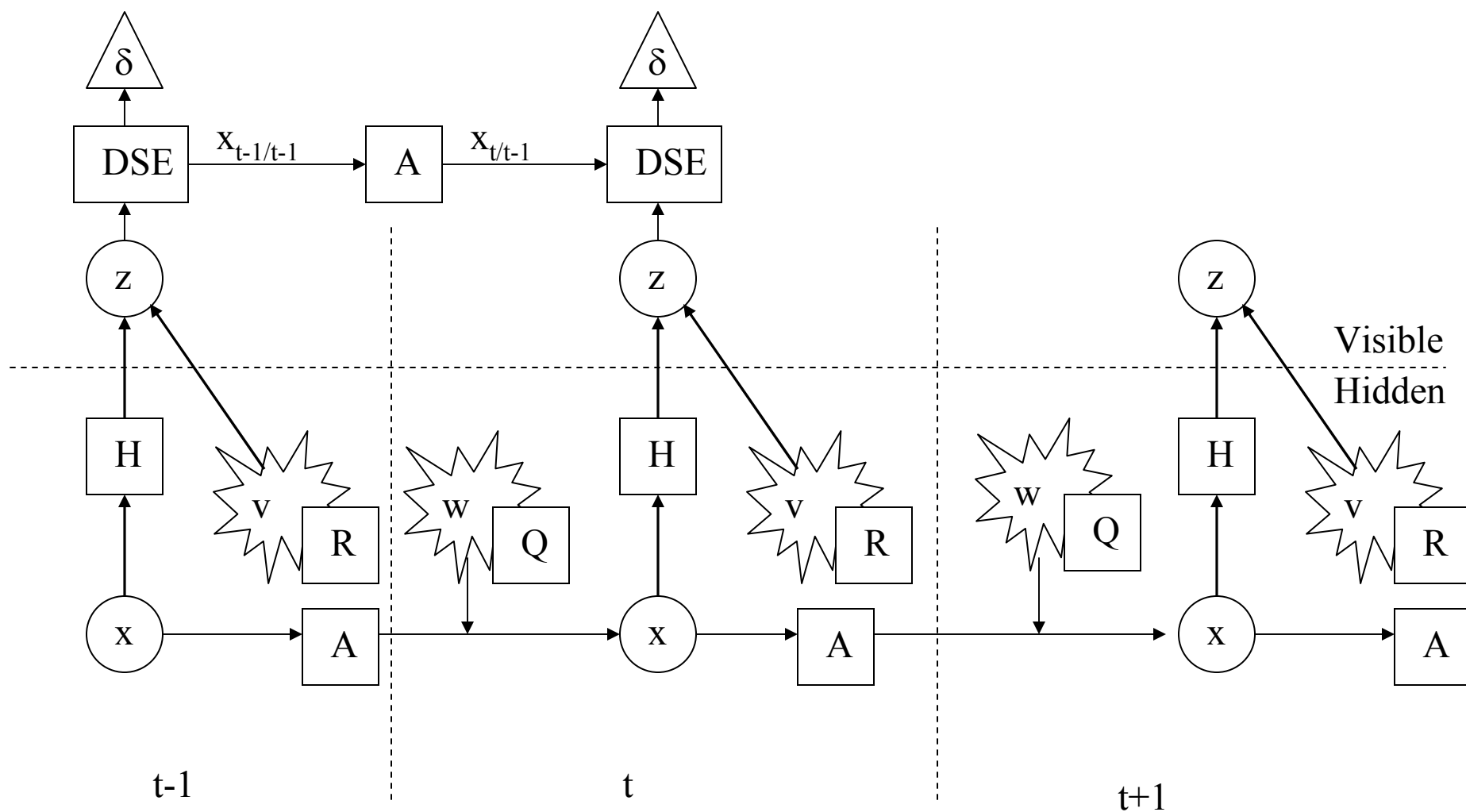
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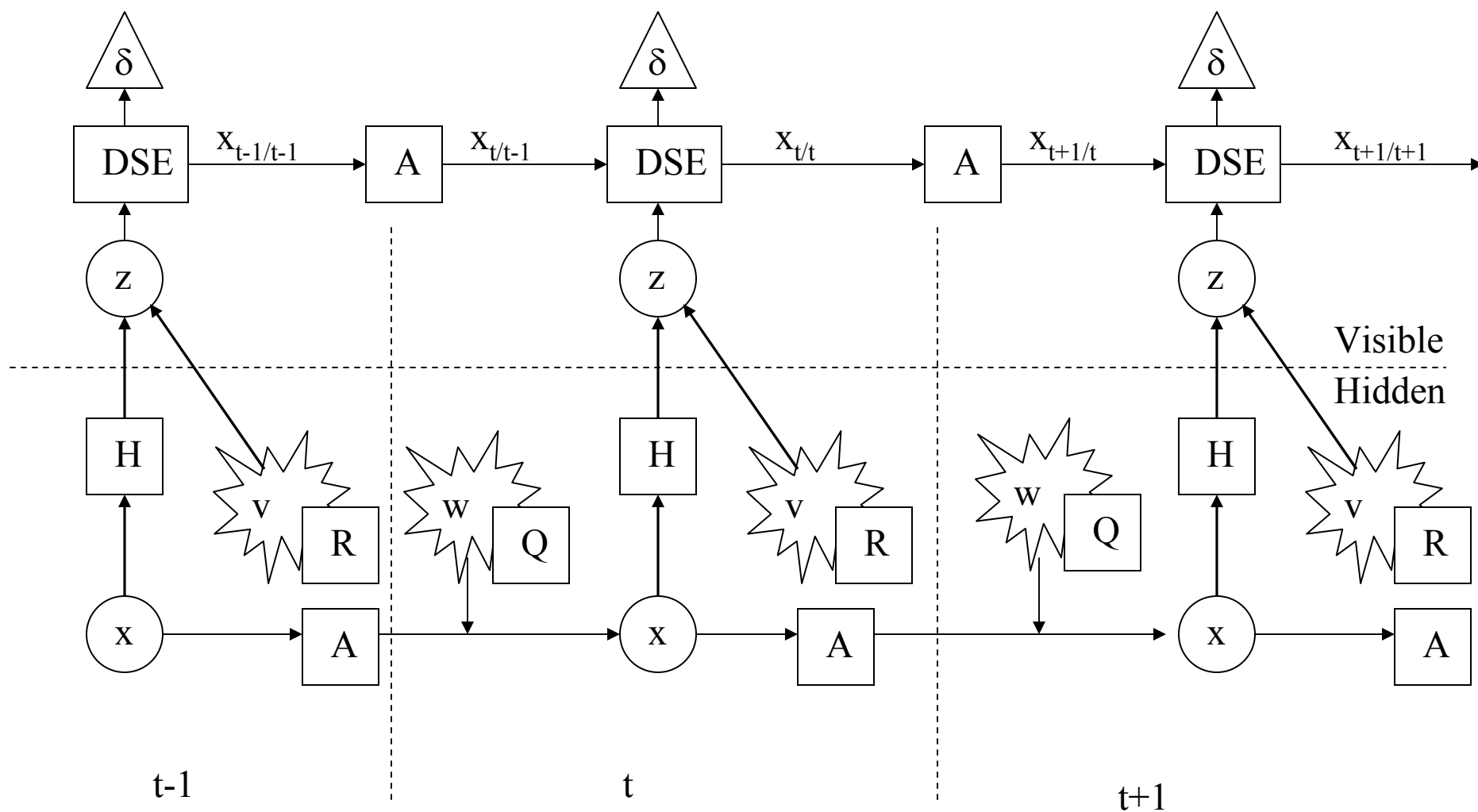
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# Dynamic Estimation

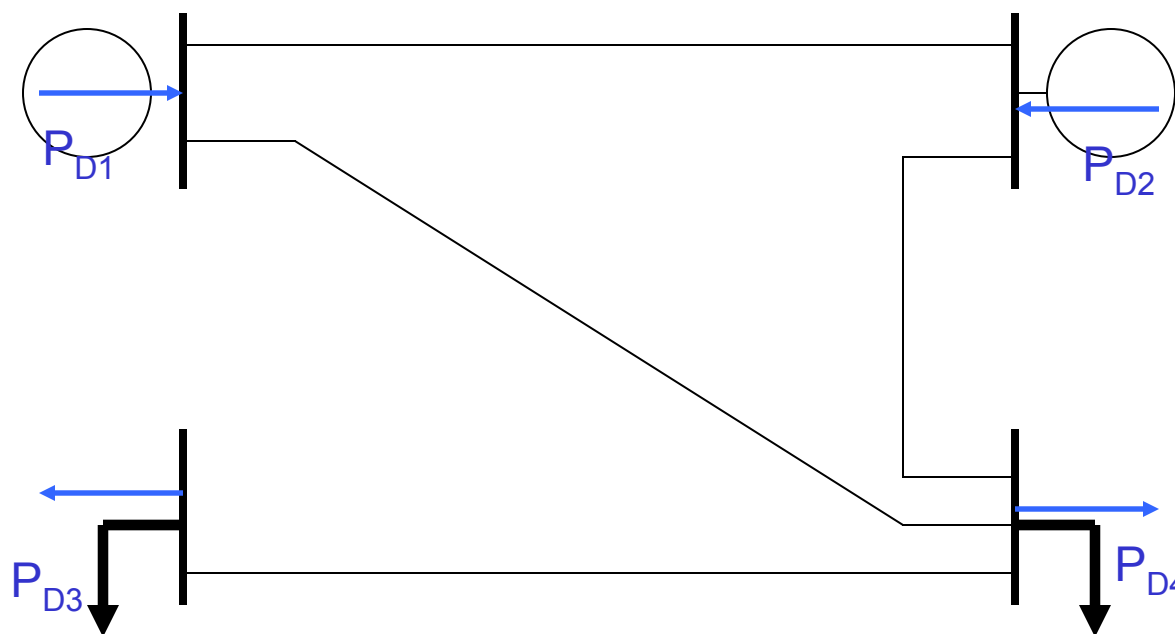


# Dynamic Estimation



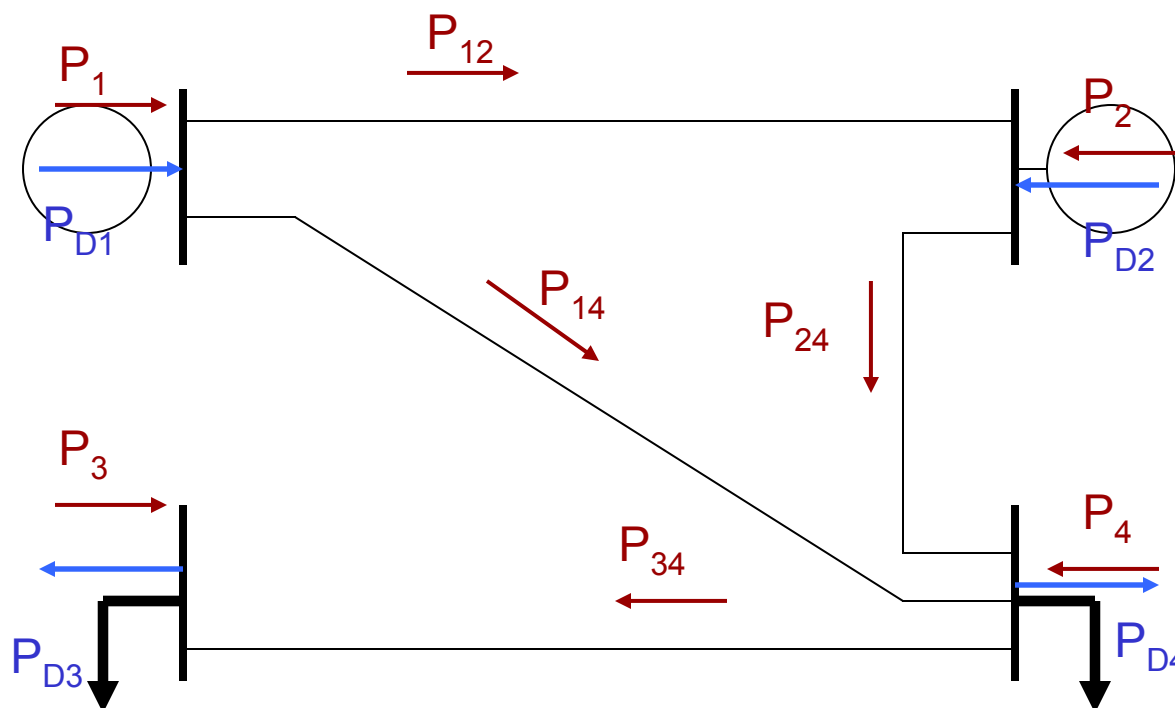
# The Network

(and attached systems)



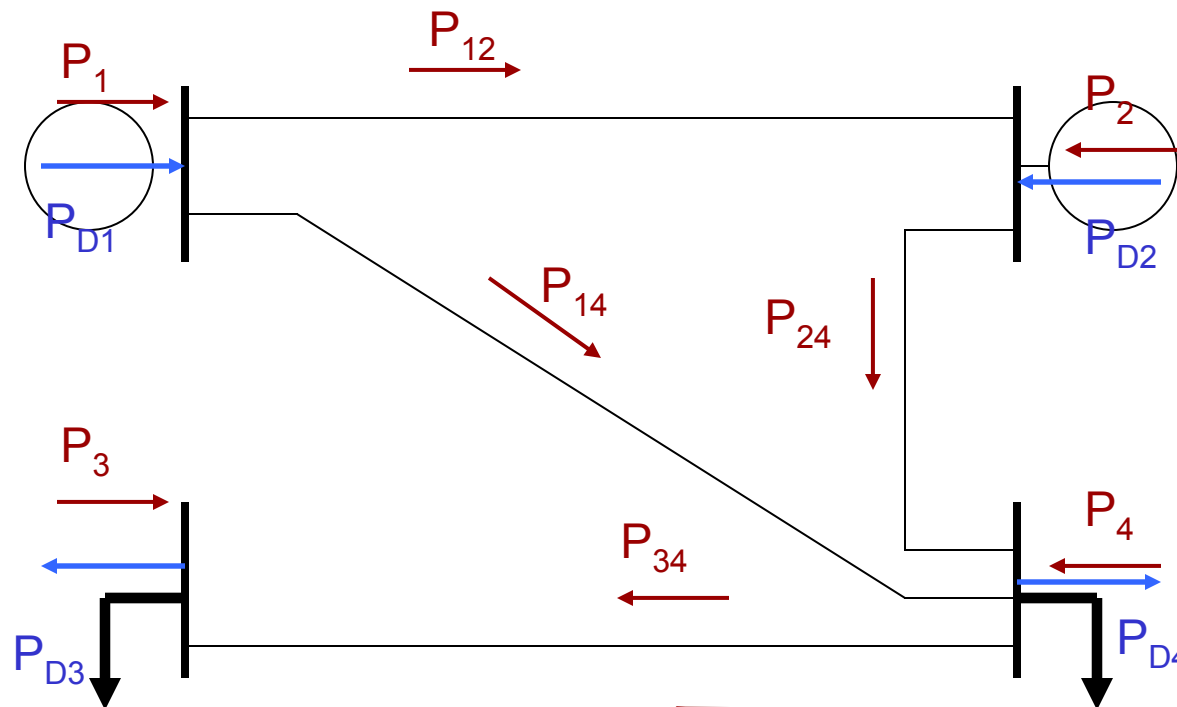
# The Network

measurements (and attached systems)



# The Network

measurements (and attached systems)



The  $P_D$  measurements will persist regardless of what telemetry data is presently corrupt

## DSE Implementation

- Bus dynamic system
  - GTG (4 sv) Valve position, mechanical power, frequency, **angle**
  - Load (3 or more sv) Power, frequency, **angle**

$$\frac{d}{dt} \begin{bmatrix} \Delta a \\ \Delta \omega \\ \Delta P_m \\ \delta \end{bmatrix} = \begin{bmatrix} -kR & k & 0 & 0 \\ 0 & 0 & 1/M & 0 \\ 1/T_{ch} & 0 & -1/T_{ch} & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta a \\ \Delta \omega \\ \Delta P_m \\ \delta \end{bmatrix} + \begin{bmatrix} 0 & -k & -k \\ -1/M & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta P_e \\ \omega_0 \\ L_{ref} \end{bmatrix}$$

- Network
  - Bus systems coupled through the network based on voltage angle
  - $P_{ab} = B_{ab} \sin(\delta_a - \delta_b)$
- State vector,  $x$ , is concatenation of bus state vectors
  - $E$  is participation matrix
  - $\delta = E x$



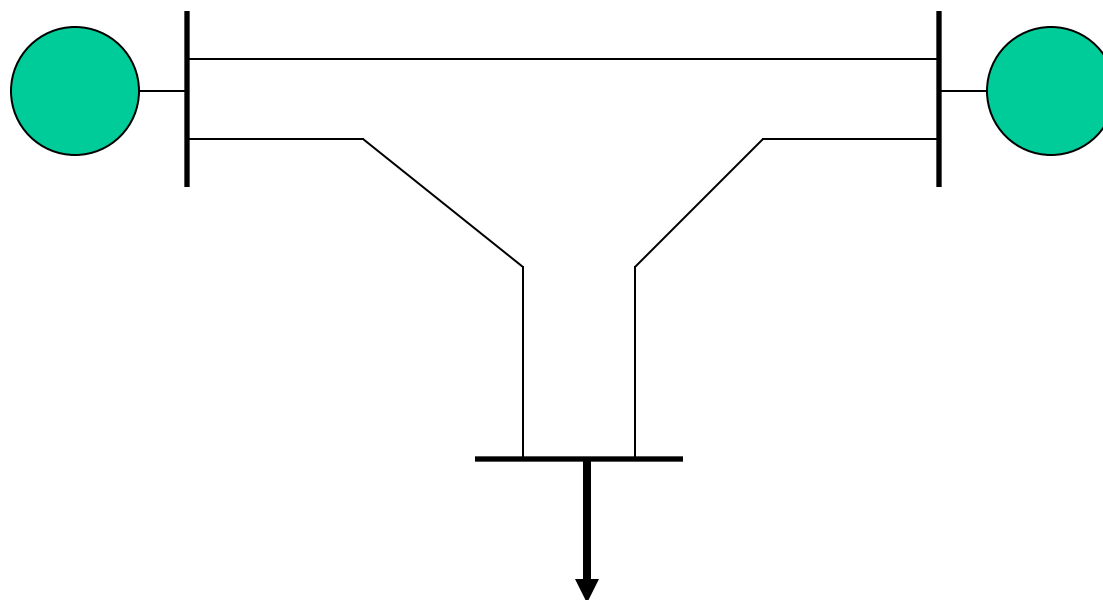
# Kalman Filtering

- KF minimizes the state error covariance
  - Linear system with Gaussian noise
  - Two steps: predict (input), correct (measurements)
- Measurements are  $\delta$ , output from static estimator
- May also have information on inputs
  - Load forecasts
  - Info from generating facilities

# SE Performance

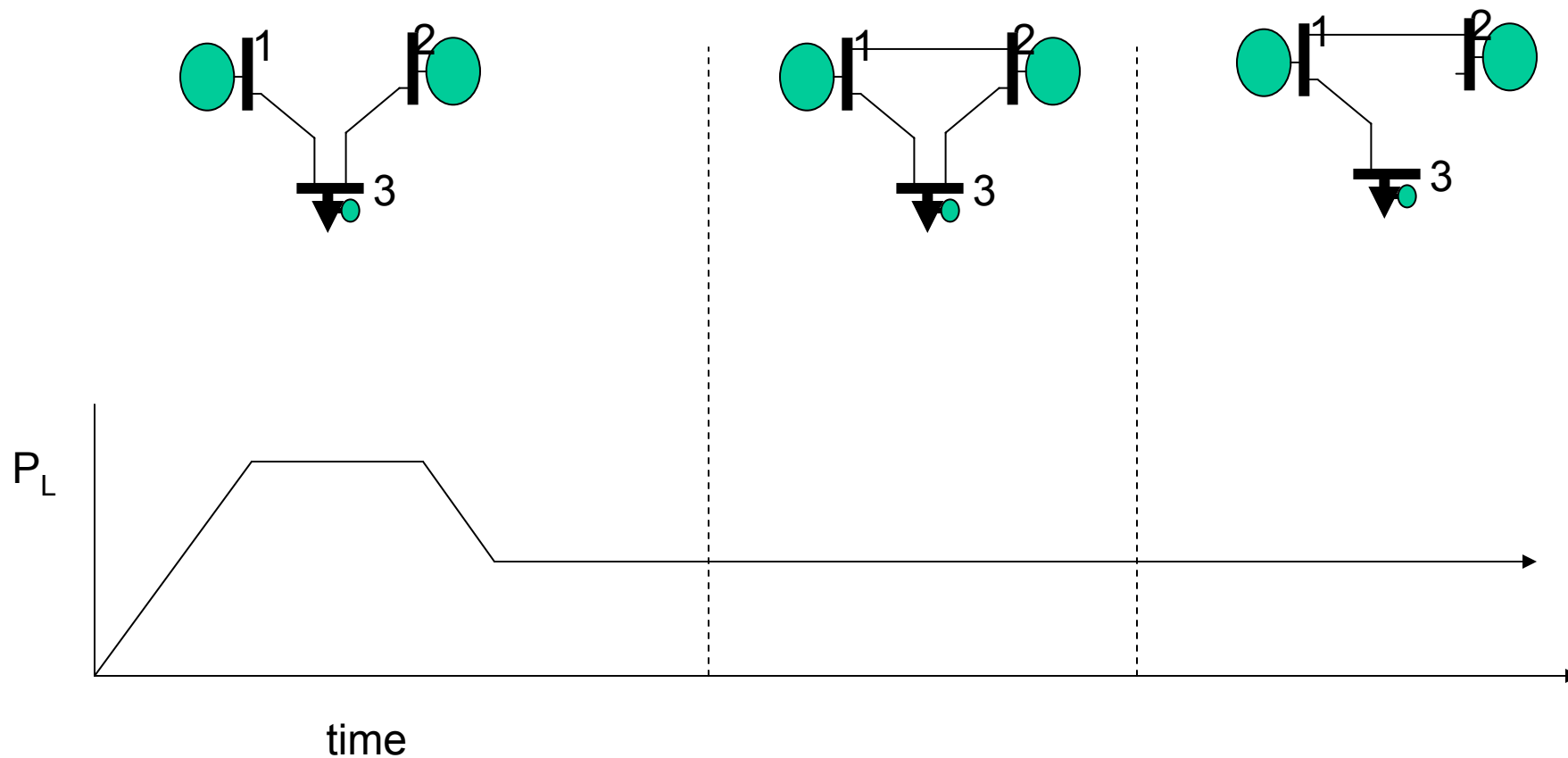
- Metric
  - SE tries to minimize state error covariance
  - Covariance doesn't make sense for unobservable state
  - Information matrix (inverse of covariance) does
  - Consider trace of information matrix as metric
- Static SE has constant best case
- Dynamic SE has worst case equal to Static SE
  - Improves as more measurements are collected
  - Degrades but doesn't fail when unobservable

# Three Bus Sample System

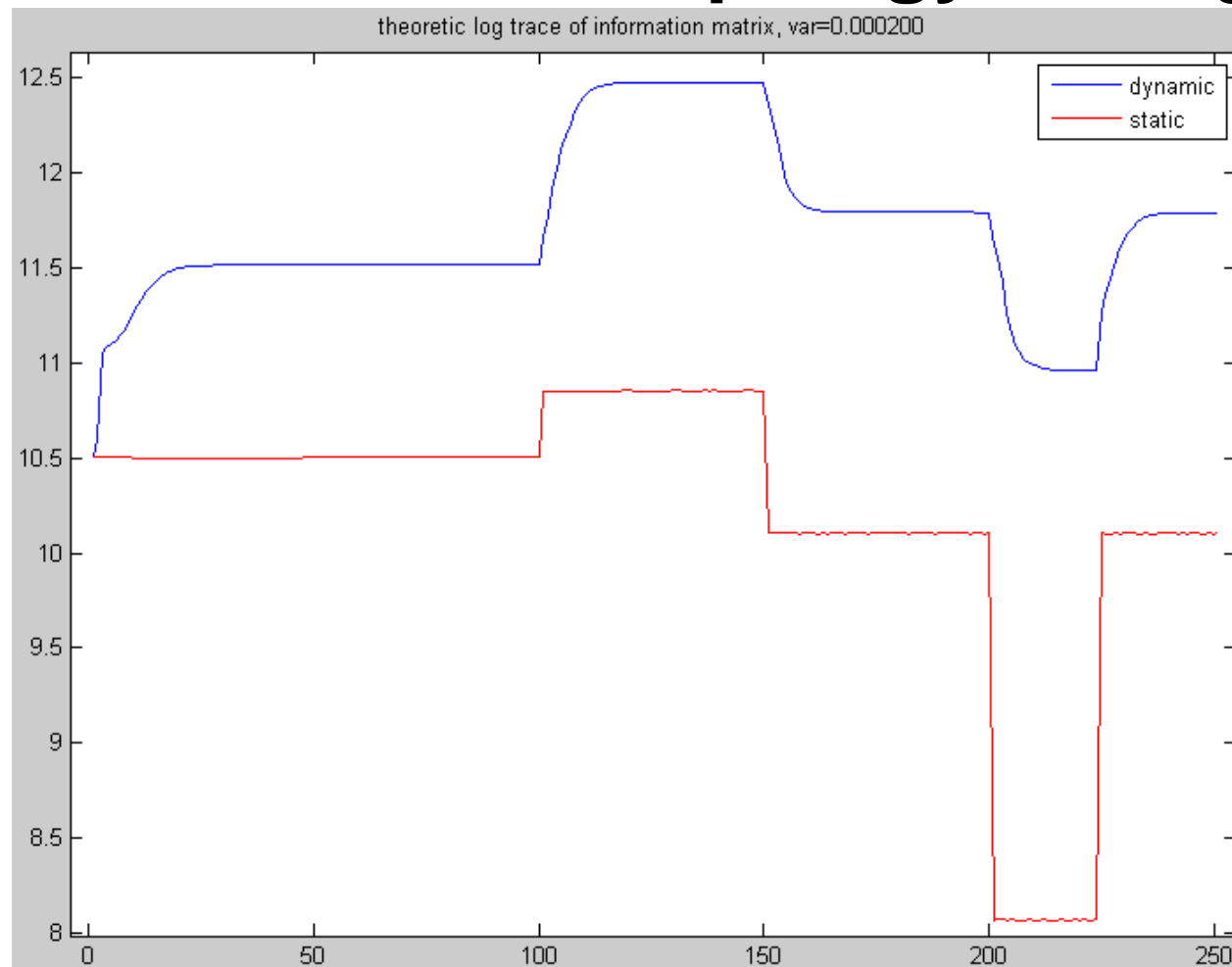


Lossless, nonlinear line flows  
 $P\delta$ , QV decoupled

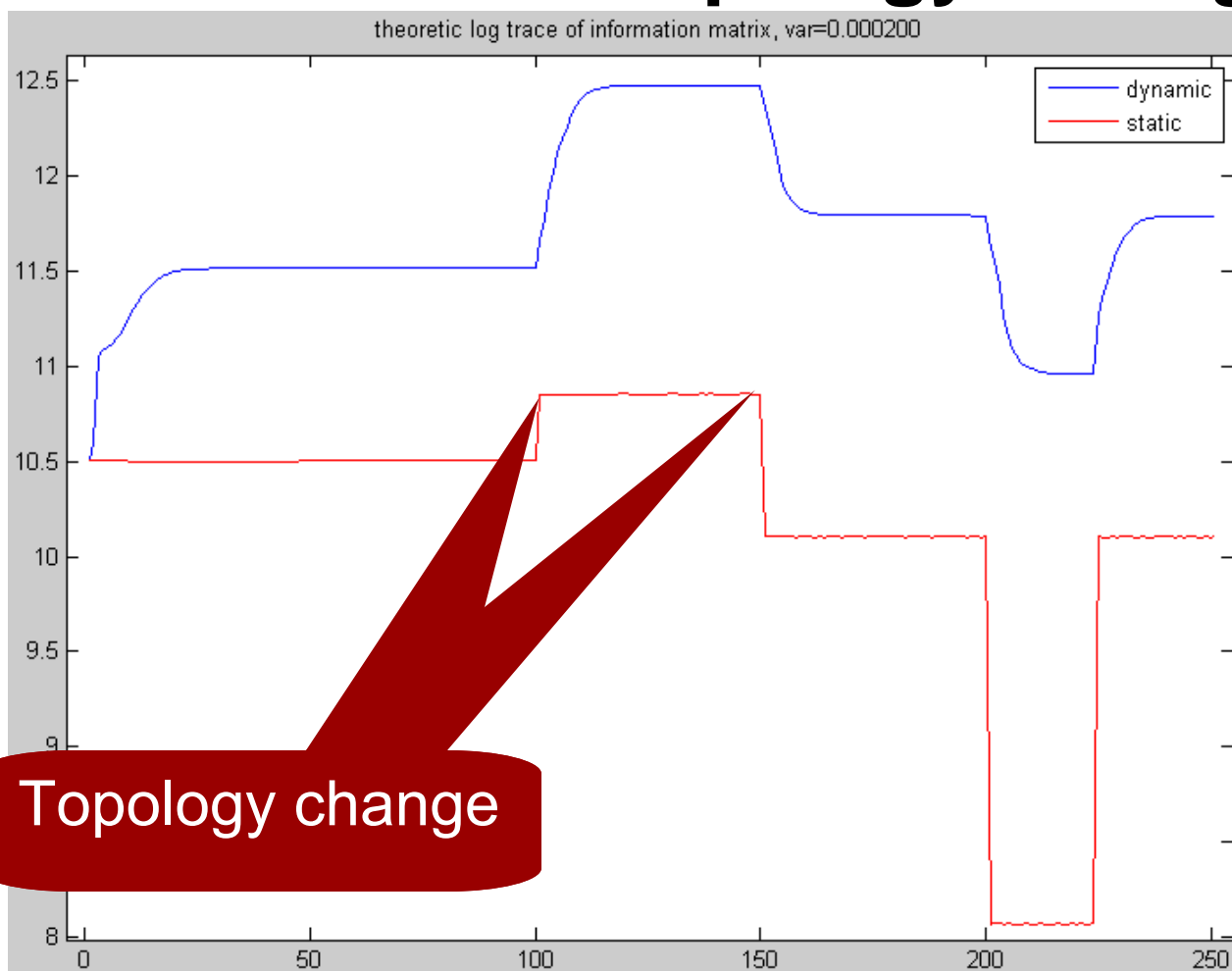
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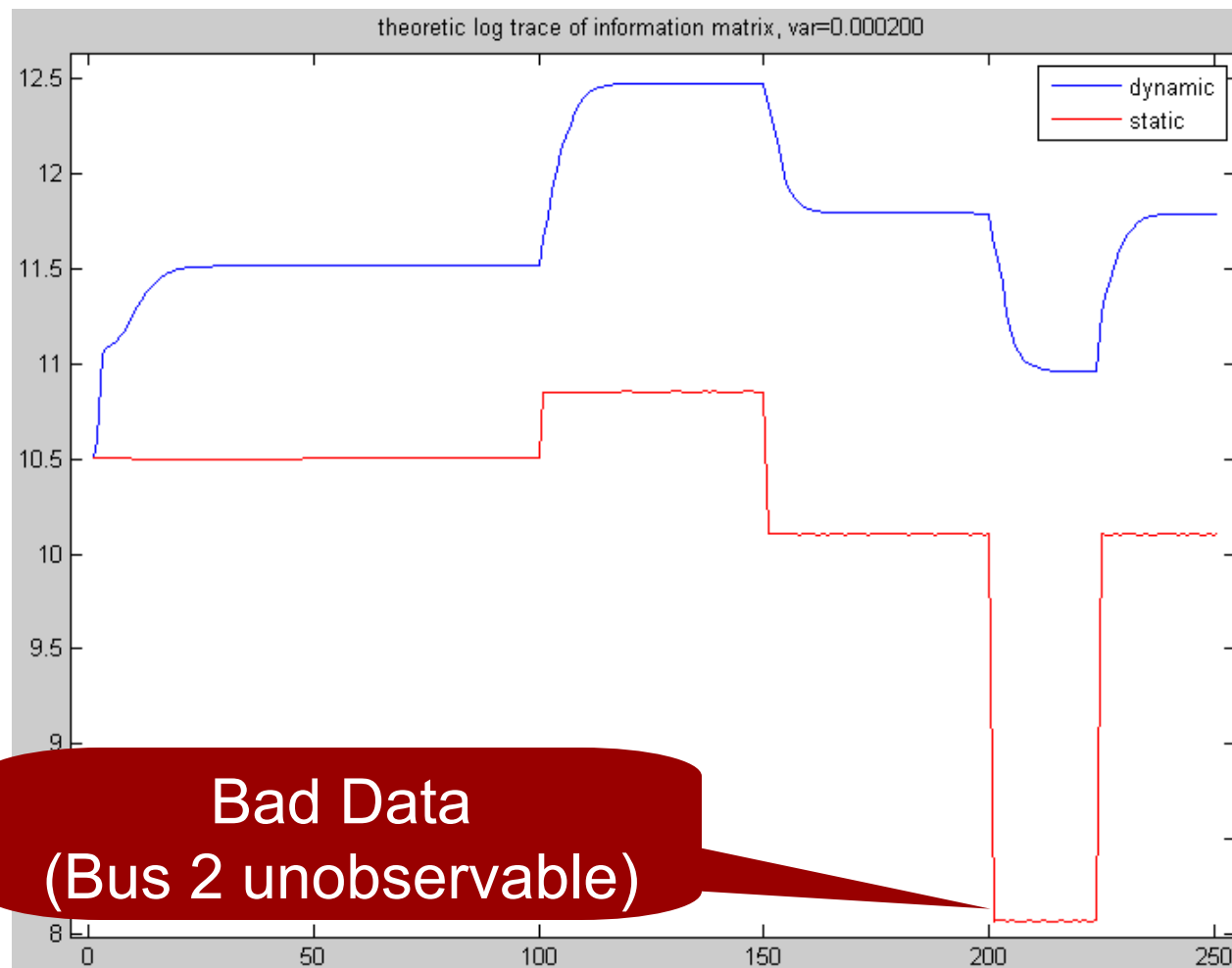
# Performance – Topology Change



# Performance – Topology Change



# Performance – Bad Data



# Conclusion

- Static state estimation
  - Provides useful and reliable information to operators
  - Heavily susceptible to bad data
  - Some states unobservable
- Dynamic state estimation
  - Provide improved accuracy over static estimation
  - Reduced susceptibility to temporary unobservable conditions



# Questions?